ROBOTIC PIPE SCANNING: INTELLIGENT INTERNAL TOOLKIT FOR CRITICAL WATER MAINS

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KEYWORDS

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ABSTRACT

Sydney Water manages a complex water network that includes 5,000 km of large-diameter critical pipelines. To maintain customer satisfaction and minimise loss of water it is essential to manage leaks, breaks through implementing an effective and efficient preventive maintenance and renewal program. Sydney Water in collaboration with the University of Technology Sydney's Centre for Autonomous Systems (UTS CAS) has developed two world-leading robotic condition assessment tools. These travel inside a dewatered pipe, providing a full 360° wall thickness scan up to 500m in length. Sydney Water has successfully deployed the tools during main failures. It also expects to apply the technology in planned maintenance inspection interventions.

INTRODUCTION

Critical Mains

At present Sydney Water's customers experience around 175 critical water main failures per annum. Aside from the service disruption, the cost of repairing these main failures can approach $10 million dollars over the year.

The critical pipe cohort mainly included pipes >300mm. As an 'avoid fail' cohort they are programmed for condition assessment prior to renewal. Up to $4 million is spent during a year to condition assess around 1-2% of critical mains leading to ~$30 million per year for renewals (excluding the cost of repairing failures).

Critical Water Main Strategy

Sydney Water has a mature approach to managing critical water mains. Renewals are targeted through a rigorous process based around advanced condition assessment and failure prediction (ACAPFP) modelling. However, it was evident that there was still a gap in the condition assessment domain with limited 'fit for purpose tools' available for internal condition assessment. Available tools also lacked rapid deployment and analysis capability to assess failed pipes in 'real time'. During a main break there is a small window to collect critical main condition data and effect a repair that minimises the likelihood of the same customers experiencing a repeat loss of service.

Condition Assessment Protocols

Sydney Water's improved condition assessment protocols involve three levels of measurements.

1. the soil and environment around the pipes to enable corrosion modelling
2. the pipe wall condition (externally) at three locations within a 1 km distance to measure remaining wall thickness to calibrate corrosion and failure prediction modelling
3. the new robotic sensing assessing the inside of the pipe to precisely measure pipe wall condition and optimise renewal lengths

Steps 1 and 2 above form the core of the ACAPFP process. Over the last 10 years, rigorous implementation of the first two levels of condition assessment has maintained critical water main performance with respect to service disruption and renewal cost.

The driver of condition assessment is to identify the pipes that should be renewed. However, there is evidence that the two levels of condition assessment was leading to renewing greater pipe lengths than necessary for an equivalent service performance outcome.

The current ACAPFP toolset can infer likely worst condition and probability of failure of a pipe from the spot condition inspections in step 2. However, they can only coarsely identify the sections to target for renewals given the inherent granularity along the length of a main.

Sydney Water and UTS CAS have collaborated to develop a set of robotic tools to enhance the current condition assessment approach (Step 3 above).

Assessment of the internal pipe using robotic sensing

While the integrity of a pipeline can be approximated from local environmental data, direct scanning of the pipe wall offers a conclusive measurement of remaining wall thickness, allowing accurate estimation of remaining asset life.

Generally, this is done by excavating and externally scanning the pipe wall, a costly and disruptive exercise. However, main failures and planned maintenance present a unique opportunity to scan the pipe wall internally while the main is isolated enabling Sydney Water to target more accurate sections and lengths of main required for renewals.

The experience gained to date with deployment of the main break robotic tool shows (conservatively) up to 30% of the lengths of pipes inspected up to 100m either side of the break) require replacement.

Also, having detailed 'along the pipe' wall thickness provides information to optimise the use of less expensive pipe lining of segments to minimise future leaks and breaks. The ability to directly measure the pipe wall thickness around a failure or through a planned intervention:

- Enables targeted renewal interventions based on 'true' condition reducing renewal costs
- avoids future failures in the pipe lengths assessed and the associated service disruption
- enables improved main screening assessment to identify vulnerable pipe cohorts for detailed assessment

<u>PROCESS</u>

Robotic Tool Development

UTS CAS has developed two robotic condition assessment tools that can travel inside a dewatered pipe, one for rapid deployment during the short time window available during a main break, and one for planned condition assessment interventions.

They provide a full 360° wall thickness scan up to 500m in length (100m for the reactive main break tool). The tools are currently suitable for cast iron pipes DN375 – DN850, with future plans including development of a mild steel, cement lined (MSCL) capable sensor and a tool for smaller diameter pipes.

Tool Features Summary

The Mains Break Pipe Wall Inspection Tool (PWIT) shown in Figure 1, is designed to assess a water main either side of a break during the brief window between a main break and its repair. It can operate in cast iron pipes between 375 and 750mm diameter, at a speed of 100m per hour[1] and reach 100m from the entry point. Information gathered can help identify vulnerable pipe segments near the break, enabling replacement as an extended and planned part of the break repair to minimising a repeat service impact to the same customers.

Figure 1: Mains Break PWIT tool and a pictorial view of it being deployed in a pipe.

The Planned Operations PWIT (Figure 2) is designed to be used in a water main during a planned shutdown. It can operate in cast iron pipes between 400mm and 850mm diameter, at a speed of 200m per hour and reach 500m from the entry point. Information gathered can be used to identify vulnerable sections and plan an appropriate replacement or relining action. This optimises the lengths of main renewed, saving significantly on renewal costs.

Figure 2: Planned Operation PWIT tool and a pictorial view of it being deployed in a pipe.

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[1] 500mm diameter pipe

Figure 3: Typical entry pit before the broken pipe is removed and the image of the reactive robot deployed inside the pipe once the broken segment is cut out

Table 1: Tool Feature Summary

Tool	Mains Break	Planned Operations
Diameter Range (mm)	375-750	400-850
Scan Range (m)	100	500
Scanning Speed (m/h)	100	200
PEC Sensors	6	12
CCTV	Yes	Yes
3D Data	Yes	Yes

Corrosion Measurement Technique

Both tools are equipped with multiple, pulsed eddy current (PEC) sensors. The robot mechanism ensures that the sensors remain in contact with the internal cement lined walls of the pipe. Interpretation algorithms analyse the signal acquired by on-board electronics to obtain the remaining pipe wall thickness under each of the sensors. Since the sensors can be rotated to any position on the pipe wall, a 360-degree scan can be completed. This scan is then assembled to generate a pipe wall thickness map on a 50mmx50mm grid which are included in the site reports.

Reporting

Following each deployment a preliminary report is generated within two days containing several types of media to provide an effective means for pipeline condition assessment. Figure 6 shows an example of the corrosion map generated to indicate remaining wall thickness. These maps indicate, by colour scale, where the worst levels of corrosion can be found and to what extent it has reduced the pipes wall thickness. Coupled with failure predicition tools this forms a valuable measure of the remaining life of the pipe at that point.

CCTV imagery (Figure 4) is also obtained during deployment to assess lining condition, other visual defects and provide live visual feedback to the opertors. Spatial data is also recorded making it possible to generate a three dimensional map of the pipe interior (Figure 5).

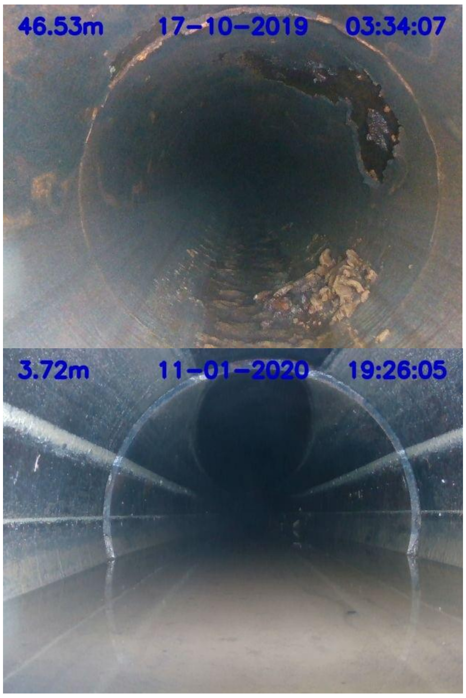

Figure 4: Examples of CCTV footage collected during scanning process illustrating damage to the cement lining and water level in the pipe

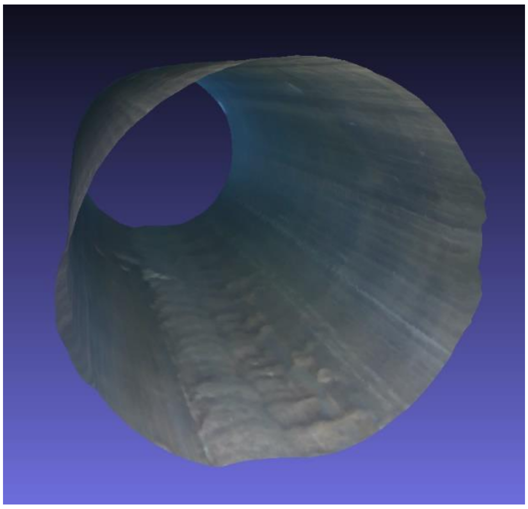

Figure 5: Three-dimensional reconstruction of a pipe segment showing cement accumulated at the invert of the pipe, possibly occurred during in-situ cement lining process.

Reactive deployment process

The UTS research team currently deploys the Mains Break PWIT based on an agreed protocol with Sydney Water designed to minimise the interruption to repair works.

Following a main break, Sydney Water assesses if deployment of the tool is possible based on expected repair window, physical characteristics of the pipeline, impact on current system operation and customer disruption. If a deployment is likely, the UTS team is supplied with pipe characteristic and failure details.

Once onsite, UTS and Sydney Water personnel coordinate to ensure the deployment and retrieval of the tool in an efficient, effective and safe manner. Priority is given to scanning the two standard pipe lengths[2] either side of the break to enable the Sydney Water team to decide whether these pipes need to be immediately replaced. The UTS team then scans as much pipeline as the conditions and timeframe allows.

RESULTS/OUTCOMES

Reactive Deployments

There were ten deployments through 2019 as shown in Table 2.

Table 2: List of Deployments in 2019

Date	Location (all Sydney NSW)	Pipe size (mm)	Scan Length	Time in Pipe (hrs)
11/02	Concord	450	2 x 35m 1 x 12m	1.5
10/04	Punchbowl	500	2 x 4m 1 x 50m	1.25
25/05	South Penrith	450	3 x 50m	4.5
21/07	Yagoona	450	3 x 30m	1.25
22/07	Guildford	450	2 x 6m 4 x 75m	3.5
24/07	Prospect	500	1 x 5m 1 x 20m	1
27/07	Bradbury	450	5 x 60m 5 x 20m	3.25
16/10	Punchbowl	500	1 x 100m 1 x 35m	1.25
8/11	South Penrith	600/750	5 x 10m 2 x 5.1m	1.5
14/12	Yagoona	375	4x33m 4x30m	2.5

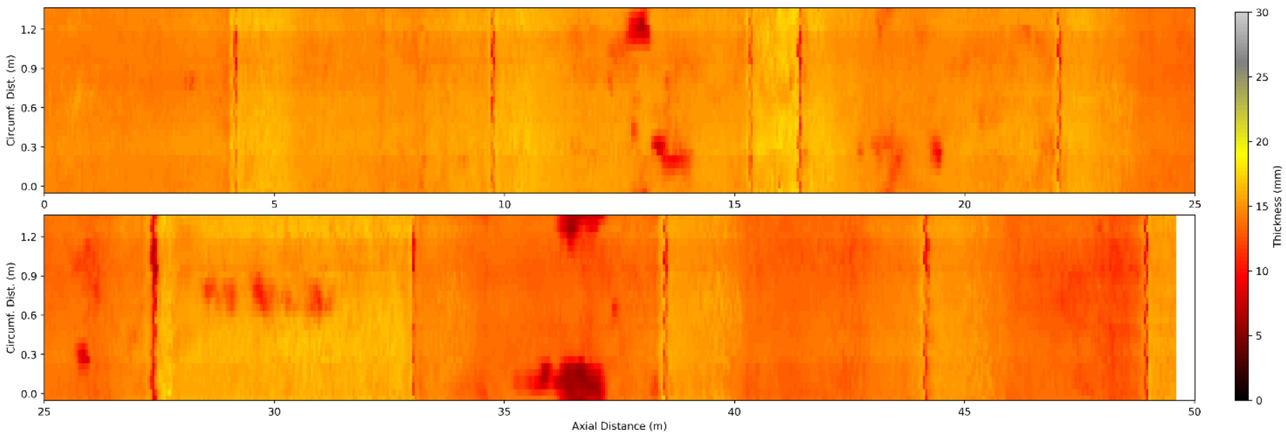

Figure 6: Corrosion Map Generated from South Penrith Deployment

[2] A standard pipe length is circa 6m but can vary

Learning from reactive deployments

- Confirming corrosion or/and weak spots occur in patches along a long length
- Evidence that a maximum of 30% of lengths are required to be renewed to achieve prevention of main breaks (improved targeting of renewals)
- Refining the robots to be more adaptive to field conditions
- Efficiency of deployment during the short window of a main break
- Improving the communication between Sydney Water and UTS to enable timely intervention when main breaks occur
- Orientation, training and learning for Sydney Water teams
- Building shared ownership between the Sydney Water and UTS teams value from the robotic tools

Planned Deployments

Sydney Water and UTS are developing protocols to enable deployment of the Planned Operation PWIT tool. This includes proactive use of the data driven prioritisation pipe model to target the planning tool intervention and use of the planning tool when pipes are cut for planned pipe replacements or lining as validation (and optimisation) of these interventions.

With greater opportunities to use the planning tool Sydney Water expects to achieve significant reductions in critical main breaks (customer service disruption) and improved renewals and relining programs that leverage available renewal budgets further.

Challenges Encountered

Minimising disruption of supply to customers is the highest priority for Sydney Water aside from the safety of its workforce and the community. The limited time windows available, particularly during main breaks, is the main challenge encountered during deployments. In the eleven deployments in 2019, time available for scanning ranged from one to five hours. The tool requires multiple traverses in order to capture a complete wall thickness map of the pipe circumference. Scanning a longer distance with just one traverse or taking multiple scans over a shorter distance is a critical decision the deployment team makes on site.

The tool is robust and could handle mud near the break, steps (minor diameter changes due to previous repairs) and debris on the pipe floor, sometimes due to localised spalling of the cement lining. However, the robot was not able to negotiate a misalignment at a joint on a relatively steep incline nor function with the pipe >40% full of water.

Although water proof, the 3D camera is not able to operate under water making it difficult for the operator to judge the conditions inside the pipe when the pipe is about 40% full.

The length of the robot limits its ability to negotiate sharp bends in the pipe. These limitations will be addressed in the next generation of the tool.

The wall thickness map displayed to the operator during operations needs to be calibrated to the characteristics of the pipe being scanned. Currently, the nominal thickness of the pipe is provided by Sydney Water based on the assessment at the site. The operator is thus presented with a ‘relative’ picture of wall thickness, which while useful, may still be conservative and lead to excess pipe replacement. A fully calibrated thickness map requires grit blasting and scanning a small piece of the pipe section from the break. Ability to calibrate the maps on site and in a reasonable timeframe is a difficult challenge that is under investigation.

<u>DISCUSSION AND CONCLUSIONS</u>

Cost benefits/Value

Information derived from the 2019 deployments indicate that at most 30% of the measured pipe lengths need immediate replacement. Given the possibility to target only the vulnerable sections of a pipe, there is the potential for 50% more critical main renewals (for an equivalent service failure risk) can be completed within the current investment of $30M per year.

Driving further value

Sydney Water and UTS are engaged in a collaboration to address some of the limitations of the current tools including the ability to safely operate in situations where the pipe is not empty and ability to negotiate bends.

The current Mains Break tool is not able to be deployed into the smaller 300mm diameter critical pipes that contribute to nearly 50% of critical breaks (Figure 7), nor can it be deployed into a ‘live’ main.

The logistics associated with planned shutdowns of critical mains and maintaining supply to customers is complex. Enabling a focus on maximsing planned tool intervention and the feasibility of developing a tool that is able to be inserted to a ‘live’ pipe are also being explored.

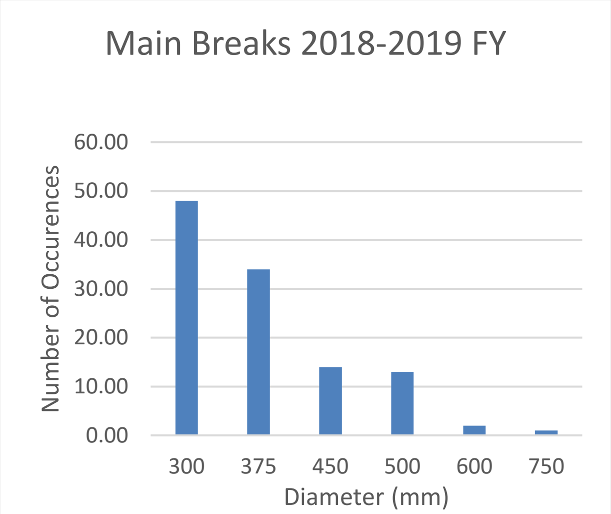

Figure 7: Categorisation of critical main breaks based on pipe diameters

Conclusions

The intelligent toolkits developed by UTS Centre for Autonomous Systems are demonstrating value to Sydney Water. The Mains Break PWIT tool enables Sydney Water to assess the integrity of assets adjacent to main breaks, intervene appropriately and prevent repeat failures impacting the same customers.

The Planned Operations PWIT tool enables Sydney Water to initiate timely interventions prior to breaks, better target and optimise renewals programs based on detailed pipe condition.

Fostering an effective partnership between Sydney Water and UTS has enabled integration of the tools into an improved approach to the management of these critical water supply assets.

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